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# INDUCTION OF ELECTRIC CURRENTS AND INDUCTION COILS.

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BY PROF. ELIHU THOMSON.

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*[A lecture delivered before the Franklin Institute, January 26, 1891.]*

The lecturer was introduced by Prof. Edwin J. Houston, and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

Since the memorable experiment of Faraday, about fifty years ago, by which he demonstrated that an electric current could produce another current by action called induction through the intervening space between the two conductors, an increasing interest has been attached to the phenomenon itself by the varied forms under which it occurs, the accompanying actions displayed and the utility of the apparatus.

One form of Faraday's experimental apparatus deserves particular notice, inasmuch as it contained the essentials of the much more modern apparatus of like character. It consisted of a ring of iron which had two coils wound on it, as seen in *Fig. 1*. He found that on passing a current through one coil there could be obtained a second or secondary current in the other at the moments of making and breaking the circuit of the first coil. These effects are now so well known that it is not necessary to dwell on them. They are examples of the phenomena of electromagnetic induction, which Faraday investigated so ably and so thoroughly that he virtually laid the foundation for

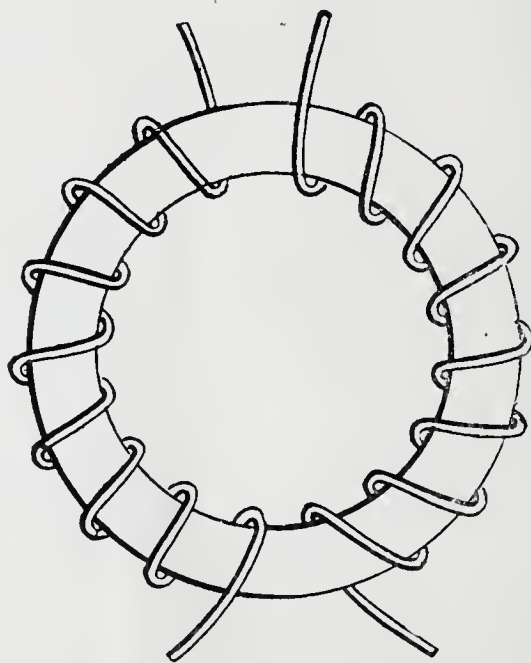


FIG. 1.

the dynamo machine, the electric motor of the present types, and the induction coil or transformer. Faraday's ring, with its two windings, is found, modified only to a slight extent, in the induction coils at present so extensively used in distribution of currents for lighting.

Long prior to these experiments of Faraday it had been known that an electrified or charged body brought near another body of conducting character, such as a metal ball on an insulating stand, would, under the inductive action of the charged body, become itself electrified, but in a special way, the nearest portion being electrified oppositely in kind of charge to the charge of the inducing body, a charge of like kind being repelled, as it were, to the more

distant portions of the insulated conductor. Without going into any consideration of these facts it will be sufficient to simply state that the principles of static induction enter into the construction of many of the most useful devices and apparatus of the electrician, chiefly in condensers.

In like manner it had long been known before Faraday's experiment that a magnet would produce other magnets inductively and give rise to changes of magnetism in other pieces of iron or steel merely by its presence near them. The experiments of Faraday showed the actions of electric currents to be similar, in that under certain conditions a current of electricity could develop a current in an adjoining conductor, or if such a conductor were not a complete circuit that it could develop charges of opposite name on

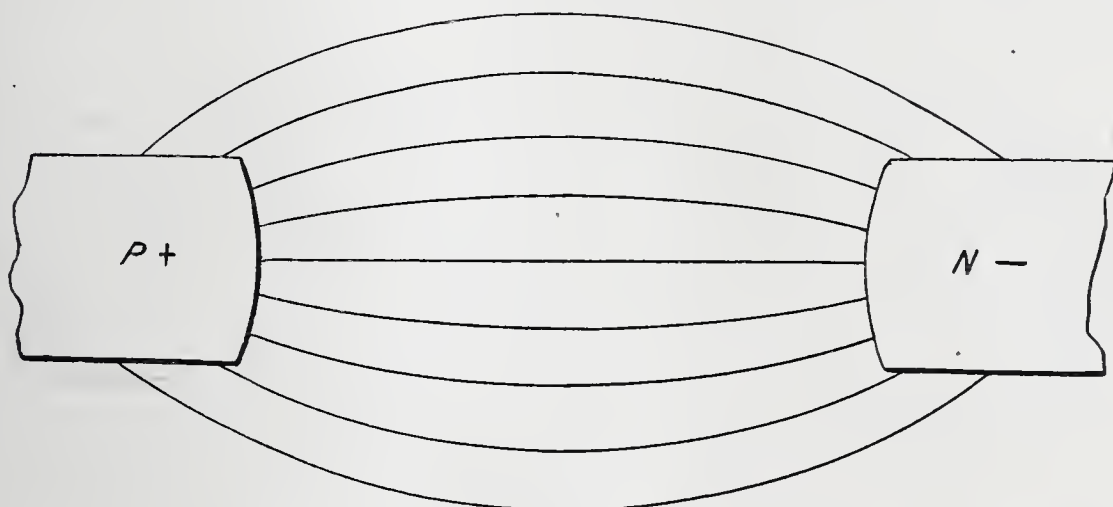


FIG. 2.

two parts of the conductor. Moreover, he showed that these effects were due not to any direct action of the current working at a distance, but in fact to the production of magnetism in the medium surrounding the conductor.

In *Fig. 2*, let  $P$  represent a charged conductor, and  $N$  another conductor connected to earth brought near to it or within a certain distance. There will at once arise a static inductional effect, whereby if  $P$  is  $+$  or positive, the body  $N$  becomes  $-$  or negative, and lines of inductional stress or electrostatic stress may be conceived as joining the two bodies as shown.

This figure will equally represent the effect of bringing an iron body  $N$  near to a magnetic pole  $P$ , in which case the lines would represent the lines of force or magnetic

lines joining the two. But suppose that the bodies  $P$  and  $N$ , when in the condition as first stated, that is, with an electrostatic stress existing between them, and, therefore, possessed of opposite electrical charges, be joined by a wire, as in *Fig. 3*.

Now, it will be found that a current will flow in the wire as assumed from  $P$  to  $N$  though the direction is a convention at present. An action in the wire occurs which we call the flow of the current and this flow continues so long as there exists any stress as represented by the lines joining  $P$  and  $N$ . But the moment of the beginning of current flow is attended by the evolution or formation of a system of forces or actions called magnetic actions and they are represented by closed bands surrounding the wire convey-

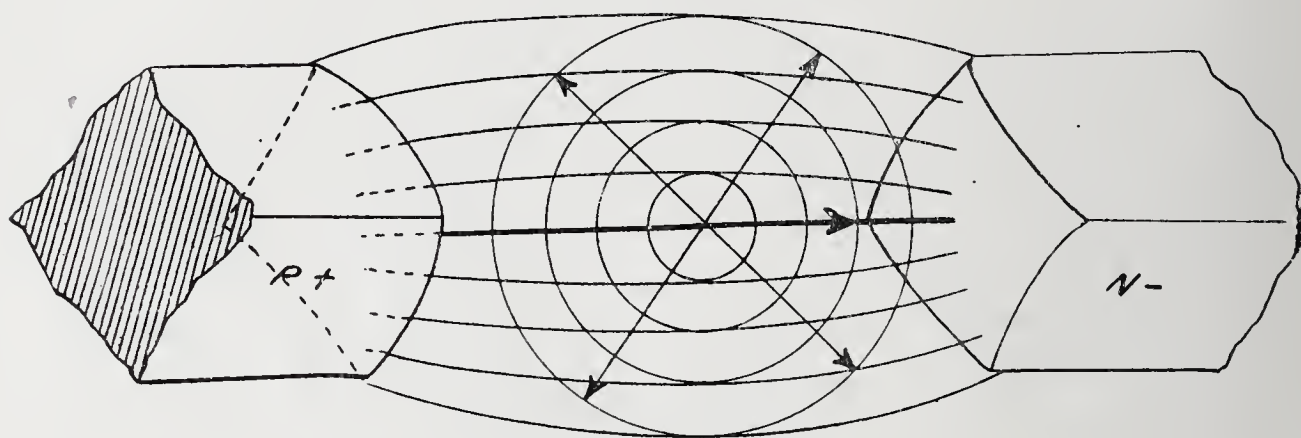


FIG. 3.

ing the current. They are at right angles at any point to the lines of electrostatic stress, and the influence which they represent proceeds outwardly from the conducting wire in a direction at right angles to both the magnetic bands or lines and to the lines of electrostatic stress and with a velocity equal to that of light, if the influence is unretarded.

The magnetic bands or whirls are the lines of magnetic force of Faraday. We then have three things at right angles, just as in space we have length, breadth and thickness, or distance. Can it be possible that in these conditions of electrostatic stress, magnetic lines, and propagation with the velocity of light, we have an exemplification of the properties of space of three dimensions, such that if we fully understood the one we would understand the

other? This is a view which is not improbable, seeing that the ether, or universal space-filling medium (or space maker perhaps), is known now to be the electrical medium.

Here then we have a harmony of effects pointing clearly to a common cause for all these actions of static induction, magnetic induction and current induction. Indeed, to-day we have learned to regard an electric current in a wire or conductor as simply a part of the thing occurring, the core, as it were, of a disturbance not limited to the wire itself, but extending outwardly therefrom in weakening force to limitless distances, and that the energy transferred by a current in a wire is conveyed, to use a sort of contradictory statement, by the medium outside the wire.

In short, we have come to believe more fully than ever before in the existence of that mysterious, all-pervading medium, the ether, and that magnetism, electricity—both static and dynamic—light and radiant heat, are things connected closely with the properties of the ether, which as a medium may be called broadly an electrical medium. We are accustomed to look to this medium also as the cause of gravitational effects, but by virtue of what property produced, and how produced, we know not. In like manner molecular and atomic attractions, cohesion and chemical affinities must be dependent on the properties of the ether, and cohesion may probably be gravitational force intensified by proximity in obedience to some unknown law. These considerations are, however, not explanations of these obscure yet most familiar phenomena.

It is not our purpose, in the present lecture, to do more than point out some of the more important effects produced by electric currents acting inductively, aside from other forms of induction, and to point out the great importance which these effects and the apparatus which yield such effects have come to occupy in the study and practice of the electrical arts.

In particular, we desire to deal with the inductive actions of those currents, the direction of which is constantly changing and at varying rates of change. Such currents are called alternating currents, the number of times per second

that the reversal takes place being called the rate of alternation, and half that number being known as the periodicity or frequency.

While the consideration of the actions occurring in magneto- and dynamo-electric machines would not be excluded by the title of the present lecture, since in such apparatus we have a case of electric current induction, yet it is thought best to confine ourselves to the consideration of the special instances in which one electric current sets up other currents or acts inductively.

Let us take first the case of a simple long wire or portion of an electric circuit through which a battery current may be sent by closing a contact or key. Close observation would show that such current did not rise at once or immediately to its full value but was very slightly delayed unless the wire were very long, in which case the delay would be quite considerable. It will have suffered an impeding action or "impedance," as it is now termed. This was Faraday's "extra current on making," in opposite direction to the current itself. Winding the long wire into a coil was found to increase this impedance and putting an iron core into the coil still further increased it. While in small coils or short conductors the action is of very slight duration, ending in a small fraction of a second after closing the circuit, yet in large coils with massive iron cores the impeding action may last a few seconds. In these cases it is said that the current develops a counter pressure to its own flow, or a counter electro-motive force.

Now let us consider the current flowing at its full value and an attempt to open the circuit or cut off the current. We have again a delaying action, a tendency of the current to force a brief continuance of its flow or to fall off gradually. This is manifested by a spark at the opening contacts which, with long and large coils, may become a flame of several inches in length. This was Faraday's "extra current on breaking"—more properly a continuance of flow resulting from a negative impedance, or addition to the pressure or electro-motive force of the current.

This effect is employed in many forms of apparatus, a

good example of which is the extra current coil or spark coil used in gas lighting by electricity. In this case a weak battery current is closed through a coil of wire wound on an iron core and the circuit carried to the gas burner, where, upon turning on the gas, the contacts at the burner are briskly separated, so as to cause an extra, current spark, which lights the gas. The battery current alone would not yield a spark of sufficient length and heating effect, and so the coil and core are introduced into the circuit. We find, in addition, that these actions are the more intensified the greater the capacity of the circuit for magnetic effects and changes. Hence, the presence of a large iron core which can gain and lose magnetism in accordance with the rise and fall of current, greatly enhances these effects, which are called oftentimes self-inductive effects, because the current itself produces them on itself. The magnetic changes, indeed, appear to be the cause of the impedance. A gain of magnetism in the surrounding medium causes a back pressure, which slows the current when put on, and a loss of magnetism causes a forward pressure or addition to the pressure of the current, which has the effect of prolonging the flow at diminishing amount and preventing absolutely sudden stoppage.

The study and knowledge of these simple facts are of the greatest importance in all departments of electrical work, from telephony to electric railways, and the property of impedance is either a bugbear or a welcome assistance in the solution of many electrical problems.

Naturally, when a current which alternates in direction many times a second is passed in a coil there is produced an impedance to the current in much more striking degree on account of the fact that such current may be considered to be a current which is started and stopped frequently, while the changes of magnetism are made much more pronounced by the reversals of the direction of current reversing the magnetic effects on which the impedance depends.

This action must not be confounded with resistance to a current, as it is altogether of different nature, for resistance has its effect whether the current change its amount or

direction or not, while impedance is present only with changing currents. The former is like a friction, the latter somewhat like inertia.

In telegraphy on very long lines with many instruments, impedance may limit the speed of transmission of signals. In telephony on long lines and with a number of coils or magnets in the circuit it softens, weakens and blurs the speech waves. Hence, in the improved telephonic instruments arrangements are made to cut out all coils unessential to speech transmission during the use of the instrument. In electric lighting with continuous currents the property under consideration, may, if not guarded against, cause damage to insulation on sudden rupture of circuits, or, on the other hand, it may be used to steady a current where such current would otherwise be subject to quick fluctuations.

Again, the property of impedance is slightly detrimental on long lines conveying alternating currents, but on the other hand it is of the greatest value in regulating and controlling the distribution of such currents, checking their flow and increasing such flow at will. Coils which may be called "reaction coils," "impedance coils," "choking coils," "kicking coils," are inserted into a circuit with alternating currents and act to cut down the current flow, not by their resistance (which is slight), but by their impedance, which may be made much or little as desired. Variable reactive coils, give a flexibility not otherwise obtainable. We must emphasize the fact that a resistance can check a current, but involves a loss of energy of the current, which energy is reduced to heat in the resistance, while a "reactive coil" can check the flow and cause loss of only a slight amount of energy in doing so. To Prof. Joseph Henry, it is believed, is due the discovery of this action of impedance in electric circuits, and a movement is on foot to call the unit measure of impedance the henry, in honor of this great electrician and scientist.

Suppose, now, that, having a coil wound upon a core, the structure is such that it gives a considerable reaction or impedance to the current. If we now wind a second coil

along-side the first and do not connect its ends to close its circuit, we shall find that the actions of the first coil are unaffected, but the moment we close the second coil there is a great change produced. Indeed, the impeding effect of the first coil is very much weakened, though it does not disappear. Here we have a case of induction of currents with another parallel circuit. We have, in fact, an induction coil, the secondary coil of which, as it is termed, is closed on itself and might be replaced by a set of rings around the first coil or a tube of copper, or the like. If we examine what occurs in the second or secondary coil, we will find that at every increase of current in the first or primary coil there is a current produced moving oppositely in the secondary, and on the cutting off of the primary there is a current in the same direction as the primary. The induction coil has long been known, and dates from Faraday's experiments, but those forms of it called Page's helix and the Ruhmkorff coils, have been used for a considerable period to obtain from a battery current sent intermittently through a primary coil of comparatively coarse wire, very high pressure discharges from the fine and long secondary wire wound parallel thereto. Such coils have also been used in medical coils in many modifications, and more recently in the transmitter boxes of telephones, to cause a low-pressure varying current to induce in the line circuit at high pressure a similar varying current representing the waves of speech.

The Ruhmkorff coil, however, in its improved and effective form, is not simply what I have described, but much more. There is a condenser of large surface attached to the primary coil on each side of the break or set of contacts which open and close the battery connection to it. The condenser, of course, is as usual simply extended surfaces of tin-foil separated by paper insulation, one surface being connected to one side of the break and the other to the other side. Its function has been described as being that of suppressing the spark, breaking the primary by taking into it the extra current or prolonged discharge which makes the spark. It not only does this, but being the

recipient of a charge in the same direction as the battery current, it discharges itself instantly thereafter and gives a reverse discharge through the primary coil. These actions are so very sudden that they amount to a very quick alternation of the primary current. Hence, the condenser is easily seen to greatly intensify the effects for which the coil is intended. It is well known that the condenser used may be made too small in surface or too large to give the maximum effects in any case.

With alternating currents passed through the primary coil the result is that we get alternating currents in the secondary coil. The applied currents are in the form of electric waves, which may be of a pitch of a few waves per second up to a large number. I have experimented with such currents up to 8,000 reversals per second, or 4,000 complete waves of current per second. In such cases the condenser is not needed, though it may under special conditions act in a measure to increase the pressure of the currents as it does in the Ruhmkorff coil. In fact, such effects have been noticed in the recent Ferranti undertaking in London, where the condenser effect of the mains for carrying the primary currents to induction coils has resulted in increasing the potential or pressure of current in London considerably above that existing at the station at Deptford, which station supplies the current. The effect, though unexpected and apparently anomalous at first, was readily seen to be due chiefly to the mains themselves acting as condensers.

Induction coils, as now used in electric lighting, are of a variety of forms and have been given a variety of names. They are sometimes called converters, or again transformers. It is a matter of taste whether one shall call them induction coils, which they are, or converters or transformers, though of the two latter names the term transformer is apparently more widely used. Such apparatus usually differs from the Ruhmkorff coil in having the secondary winding the coarser wire of the two, and, consequently, their function usually is to take a higher pressure current supplied from a station and lower it for use in working incandescent lamps on the local or secondary circuit.

The actions of transformers may be briefly described, though a book might easily be written extending into many interesting details of their structure and performance—most of which would be out of place here. The modern transformer consists of two coils and an iron core for the coils. The core may be a closed core, as when the iron of which it is made is carried over the outside and connected into a closed band or closed magnetic circuit, or it may be an open core, where the magnetism passes into the air in completing its path between ends of an iron core, which are separated some distance. These differences introduce differences of action, which will not be discussed now, as they are largely of a technical character.

Suppose, now, that such a structure has its secondary coil open or unconnected with lamps. In such case, if an alternating current be passed in the primary coil of the apparatus, it “reacts” only. It displays the action of impedance as referred to before. This, with a well-proportioned coil, limits the current which passes to a very small amount, which current, small though it be, does not even then represent a waste of current energy except in small part. If, now, a lamp be lighted by connection with the secondary coil the current required for it is induced from the primary, but this action partly takes away the impeding action, and, as a consequence, the current taken by the primary from the line is proportionally increased. This assumes the case of constant pressure of current on the mains, the condition aimed at in practice.

As lamp after lamp is added in multiple or parallel connection in the secondary circuit the primary impedance falls off, and is only restored when a corresponding increase in the primary current takes place, together with the increase of current in the secondary. This means that if one ampère of current produces ten ampères on the secondary at a pressure of one-tenth of the primary circuit pressure, each increase of an ampère in the secondary coil would cause an addition of one-tenth ampère to the current in the primary coil. Briefly, the reason for this is that since the current in the primary is subject to impedance due to magnetic

changes produced in the iron core, and the secondary current, as it increases, tends to lessen the magnetism and consequently the changes in it, the impedance to the primary current is likewise lessened and the primary current increases to an extent such as to overcome the opposition of the secondary currents and restore the varying magnetism to its original amount. In the majority of transformers, also, the current induced in the secondary is at any moment moving in the opposite direction around the core from that of the primary current waves, and so acts to oppose the effect of the primary in magnetizing the core.

It would take up too much time and carry us beyond the

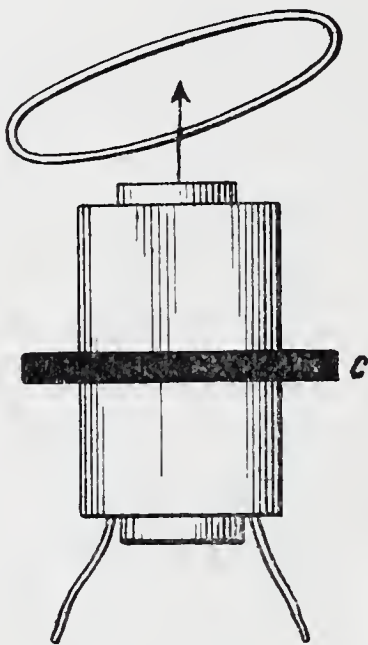


FIG. 4.

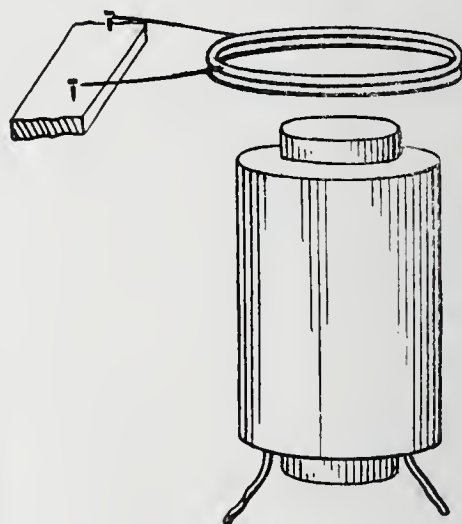


FIG. 5.

limits of the present lecture to study the effects of the lines of magnetic force in these instances. It must suffice to state that the actions of transformers are beautifully exemplified and made clear by such a study and the regulating actions just described are seen to depend on the interaction of the currents in the two circuits, occurring through the lines of magnetism or the magnetic field which they jointly set up.

In the case of a transformer put upon closed circuit, *i. e.*, with its secondary circuit or coil ends connected solidly together, the impedance or reaction in the primary almost disappears and if working as in practice, the primary and also the closed secondary circuit would receive current

in such large amount as to overheat and destroy the coils unless safety cut-off appliances were provided.

This is exemplified by an experiment easily tried. A closed ring of copper is placed over the upright coil and core *c*, *Fig. 4*, here, and alternating currents passed through the large coil which is now the primary. Currents of great vigor are set up in the closed ring and may rise to a value in heating effect such as to bring the ring up to bright redness, or even melt it. The energy is abstracted by the ring not from the air but from the ether surrounding the coil and core. If, however, the ring be free to move and not exactly over the centre of the coil and core it will be thrown

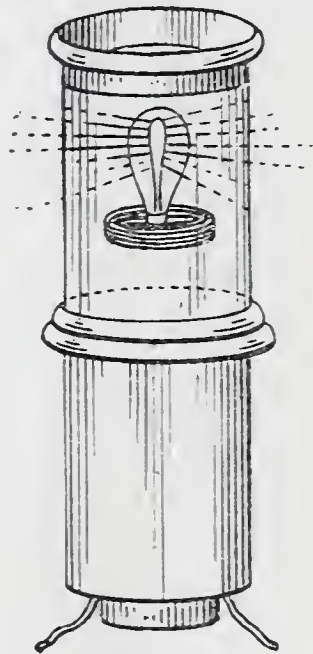


FIG. 6.

violently away or repelled and thus saved from overheating. These repulsive effects of induced currents are so striking and varied that it will be of interest to study them further.

It will be found that a copper ring or plate placed over the end of the coil, the core of which forms an alternating magnet, will even be supported for a moment in free air, or if guided laterally will remain suspended. The suspended ring will uphold one or more other rings placed near it, and will attract them into parallelism with itself, *Fig. 5*. Closed coils, pieces of metal, coins, etc., may be repelled from the field in this way.

A small incandescent lamp and coil, *Fig. 6*, suitably mounted and partly balanced in front of the pole, will be lighted and

at the same time be repelled in such way as to give a uniform brilliancy, whatever the strength of the current in the primary, or independently of variations of the same. If the lamp and coil be floated in water in a glass vessel placed over the alternating magnet pole the lamp is lighted and floated under the water by the repelling effect, and regulates its position and brilliancy as before. The magnetic waves leaving the pole, of course, penetrate the glass and water without hindrance. Interposing a heavy plate of copper between the pole and lamp coil will cut off, or screen off the effect, for the reason that the magnetic waves are then intercepted by the heavy sheet and beaten back or reflected by it. From these experiments it will be seen that there is a strong repulsive effort exerted between the primary and secondary coils of a transformer where the two lie adjacent on the same core. The reason of the repulsion has been discussed in various publications, and been shown by me to be due to lag or displacement of phase, as it is termed. Briefly, it depends on the fact that the primary and secondary currents are for the most part in opposite directions of flow around the core during each wave of current, and each current tending to produce a magnetic field which opposes that of the other, results in repulsion of the coils or circuits in which such oppositely moving currents circulate.

Following a suggestion of the Secretary of the Institute, I have improvised an experiment which I am told is very similar in effect to a "mystery" shown in connection with a "certain motor" which has been before the Philadelphia public for the past seventeen years. I bring forward this experiment with no hope that it will revolutionize modern methods or give us power for nothing, as the certain motor, or perhaps uncertain motor, is claimed to be able to do when developed. On the table is a tall glass jar, a sort of hydrometer jar, which was found in the room adjoining this hall. It rests on a table or rather on a heavy glass plate laid on the table, as you see. In the jar is a body which has sunk to the bottom of the water which fills the jar. It is a glass bulb loaded with a few turns of bare copper wire coiled up and heavy enough with the bulb to just

sink. At my command you see the body rise briskly to the top of the water, a distance of twelve inches, and sink again at my indication that it shall so act. I have no need to sound "sympathetic" notes or "antipathetic" notes as I am informed is sometimes done in connection with the "certain motor mystery," which no one is allowed to investigate. My assistant simply closes or opens a switch which sends an alternating current into or cuts it from a concealed coil just below the table top, a coil which I found as a part of the stock of insulated wire in an electric supply shop near this hall. I have taken no especial pains with this experiment and I am informed by Dr. Wahl, your Secretary, that the effect is strikingly like the "mystery" alluded to above. There are other ways possible in which such an effect might be obtained by simple means, but their discussion would be foreign to the subject in hand.

Some time after I had discovered this repulsive action and prepared to investigate it more fully, it occurred to Mr. M. J. Wightman, an associate, and myself, to try the effect of closed circuits or bands subjected to the induction of an alternating magnet, on copper discs, bands, or pieces of iron. It was reasoned out that these would move if allowed to do so. A great variety of novel and striking experiments was the result, some of which it is my purpose to present. They admit of almost indefinite extension and amplification; and it would not be possible in the time of the lecture to do more than allude to the explanation of some of the more typical actions.

They may for the greater part be regarded as effects of movable secondary circuits of induction apparatus.

Taking our upright core and coil, and placing over a plate or ring of copper *S*, *Fig. 7*, so that the centre of the ring or plate does not coincide with that of the pole, we have a magnetic field resulting which possesses novel and interesting properties. I call the pole a "shaded" pole or pole of shifting magnetism. It may otherwise be described as a pole in which the shaded portion of the magnetic field is lagged at each impulse of current in the coil behind the portion unshaded or free.

Naturally, the shading of the pole may be of a simple or complex character, as desired.

Placing a pivoted disc *D*, of copper, flatwise over the shaded pole so that its axis is to one side of the pole and approximately in line with the division between shaded and unshaded portions results in rapid rotation of the disc towards the shaded portion, *Fig. 7*. The direction of revolution of the disc may therefore be governed by shading the pole to the right or left of the axis of the disc. An iron disc *I*, *Fig. 8*, is revolved if held vertically over the region of the pole shaded by the closed ring or plate, or over any part of the pole near the junction of shaded and unshaded portions.

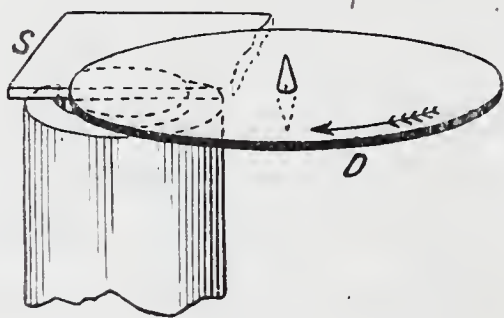


FIG. 7.

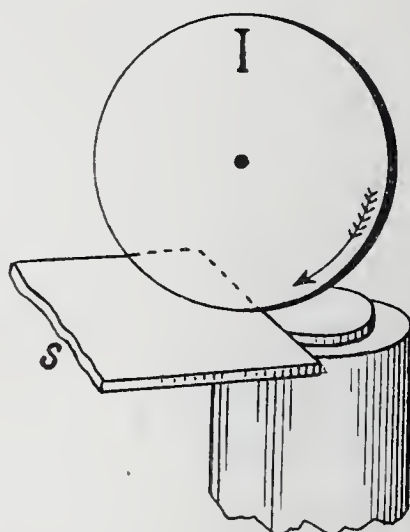


FIG. 8.

Two copper discs, laid one overlapping the other and free to turn, *Fig. 9*, and directly over the pole (in this case unshaded), are both set into rapid revolutions in directions depending on their positions over the pole.

These experiments with one or more discs and with shaded and unshaded poles may be greatly extended and a great variety of effects of rotation produced. Copper and iron discs may be used together and caused to rotate by their mutual influence on each other in the field. In this case the discs are generally placed in planes at right angles, the plane of the copper being transverse to the magnetic lines leaving the pole, and the planes of the iron disc being in line or coincident with their direction.

The copper discs may be replaced by hollow balls, *Fig. 10*, which rotate in a variety of ways. Thus, by shading the pole

and placing a copper ball over the shading plate, the ball is vigorously rotated on an axis depending on its relative place over the pole and shading plate. A certain thickness of shading plate gives the best results. The ball may revolve on a horizontal axis or with its axis either inclined or vertical. When turning with its axis horizontal it rubs its equatorial portion at great speeds over the shading plate.

A modification of this experiment is made by placing the ball in a vase of water supported over the pole shaded as before. In this case the ball rotates vigorously in the water. If a copper dish be added, and a second ball, all

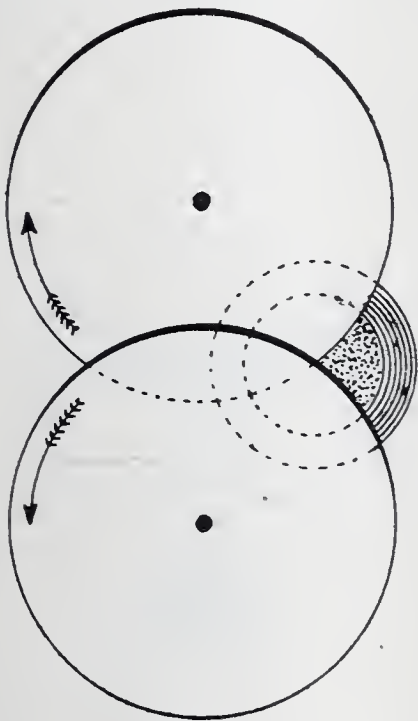


FIG 9.

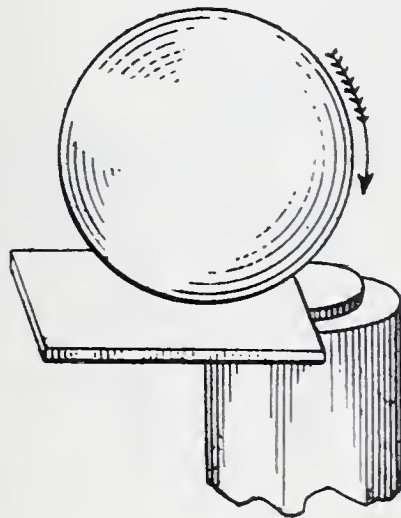


FIG. 10.

three may be maintained in a vigorous and confused activity by the shaded pole. The actions in the disc and balls are the direct consequence of the shifting magnetism of the pole, whereby as it were the lines of force act as veritable magnetic brushes to brush the discs, balls, etc., around. The hold which the lines get in the copper in causing its rotation is, of course, due to the production of induced currents in it by the moving lines of magnetism or developing field. The effect on the iron discs is due to magnetism rather than to current, the iron discs resisting slightly a change of direction of magnetization in them, which results in the shifting lines dragging the discs

around in the direction of shift or towards the delayed or shaded portion of the pole.

Some of the most curious effects are obtained by placing various shapes of iron or steel pieces over the pole and then testing them with the approximated copper or iron discs, *Fig. 11*. Few dispositions will fail to cause rotation of the discs. A more sensitive rotator, however, is a shaft mounted on delicate pivots and carrying a wheel composed of a few small discs of sheet-iron with an attached heavy copper rim overhanging the iron discs, and shown in section, *Fig. 12*.

If this device or if copper or iron discs alone be applied in the proper way in the neighborhood of pieces of iron, copper, or even brass laid on the pole, rotative effects are

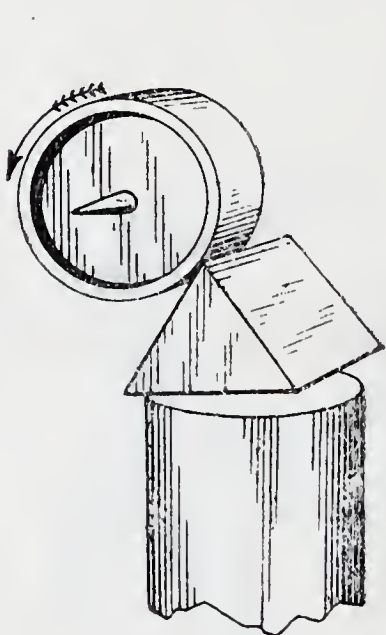


FIG. 11.

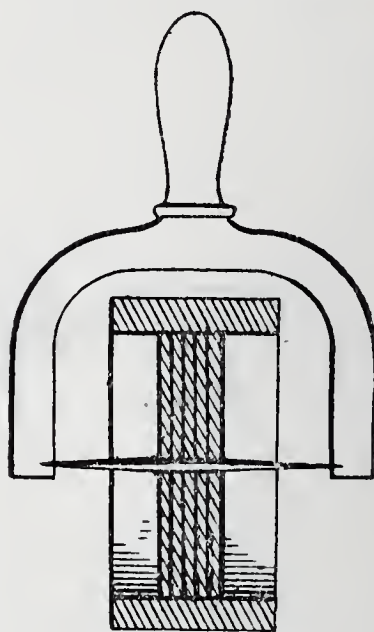


FIG. 12.

readily obtained. Thus, a steel file laid over the pole, as in *Fig. 13*, will rotate the iron discs in the direction of the arrows when they are mounted as shown, and copper discs are rotated likewise when placed near and flatwise to the file.

In this case the hardness of the steel of the file compels the magnetic change of polarity, originating at the pole, to spread laterally in a retarded manner similar in effect to the shading spoken of, but differing in cause. The shading plate of copper acts by the currents developed in it; the steel mainly by its hysteresis or resistance to changes of magnetic state, an inherent property of hardened steel.

Bent pieces of steel laid over the pole vary the actions in many ways that are quite interesting.

As a curious example of a combination of electric and mechanical actions in one device, we have an electric gyroscope constructed of a copper-rimmed rotator with iron plates or discs mounted on a shaft, a closed circuit frame of copper surrounding the same and an arm with jewel cup and counterbalance weight. This is mounted, as shown, over the alternating pole on a steel pivot set therein. Very soon the wheel of the gyroscope is set into rapid rotation and then the apparatus exhibits all the characteristic movements of the gyroscope, independently of the electric actions.

The fact that in the actions described above we obtain motion of rotation or translation is sufficient to indicate

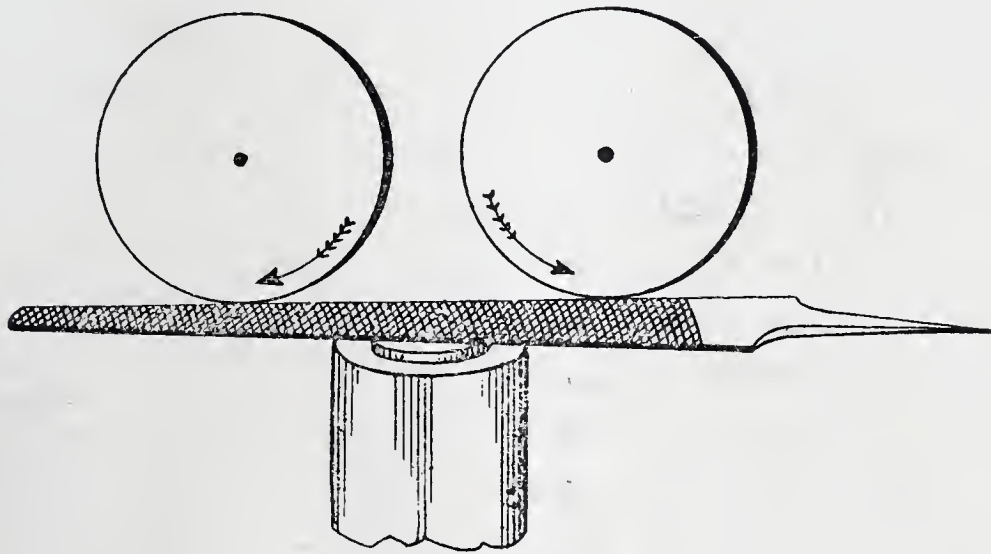


FIG. 13.

that electric motors operating by alternating currents may be constructed in accordance with the same principles. Alternating current meters have also been made in which the rotary actions have been employed to move a register at a rate depending on the current flow or consumption.

I have here one example of a small motor in which the moving part is a heavy copper disc entering the slot in a ring core upon which is wound a coil traversed by the alternating currents. The magnetic poles on each side of the slot are shaded progressively from the under side up by enclosure in copper bands let into the face of the poles. A considerable rotative force is thus obtained. Removing the disc armature of this motor and placing a silver coin at the lower edge of the slot results in the coin being lifted up and

projected from the slot above. A disc of base metal, such as lead, is not so projected while a copper disc behaves like the silver. The instrument might be arranged to quickly sort genuine silver coins from base coins, though a silver-plated copper coin would be affected about in the same manner as the alloyed silver, but pure copper would be lifted somewhat farther for the same weight and diameter of disc.

These experiments are primarily based upon the alternating magnetic field set up by an alternating primary current in a coil, and which field is modified by closed secondary coils or circuits, or by the presence of steel pieces in the field in such a manner that a portion of the field develops its effects before the other. To put it differently, a lag is set up in a portion of the field. The closed coils or plates used as secondary circuits have currents induced in them which oppose the magnetic changes tending to be brought about by the primary currents and delay such changes in that portion next to the said secondary circuits. In like manner the presence of hard steel pieces which resist change of magnetism have a similar effect in retarding the development of magnetism at each change of its direction, at the place where such pieces exist, while all around them in the air the field is comparatively free to obey the primary impulse. There results from these conditions a propagation, so to speak, of magnetism or magnetic polarity which may act on other closed circuits, or on other pieces of iron or steel to set them in motion. The movement so obtained is brought about by the continual readjustments of the moving secondary or iron piece to the shifting or propagating magnetism.

The copper rimmed iron wheel, *Fig. 12*, is so delicate a detector of shifting magnetism, that it responds to the effects of any feeble shifting which may occur in the iron core around which the primary current passes. In fact, different forms of core, whether of iron wire bundles, or of laminated structure, as bundled sheet iron, each give their own peculiar effects of shifting magnetism in accordance with the form, material and relation of the parts, and their

liability to eddy or foucalt currents or hysteresis in various positions or directions. Few cores indeed fail to show decided effects of shifting lines of magnetism at some portion of their surface, and a laminated core may be readily distinguished from a wire core by this little wheel, delicately mounted. In fact, it may be regarded as an alternating field explorer, and its indications may be of considerable value in locating sources or conditions of loss by foucalt or eddy currents, or by hysteresis.

It has been necessary to be brief in the descriptions given in this lecture, as the time has been too limited to do more than furnish food for study to those who are sufficiently interested in this important subject of current induction, in which so many developments have taken place in the recent past. The future has, of course, very much more in store.

